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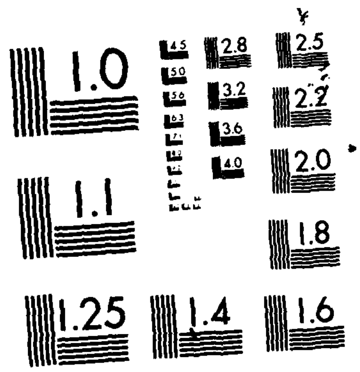

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SOME CLIMATOLOGICAL FEATURES OF ATMOSPHERIC DIFFUSION CLASSES AT NANJING

by

Zhang Shifeng, Zhao Ming, Wang Yanchang

FOREIGN TECHNOLOGY DIVISION

86 10 6 05

HUMAN TRANSLATION

FTD-ID(RS)T-0692-86 16 September 1986

MICROFICHE NR: FTD-86-C-002189

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English pages: 15

Source: Nanjing Daxue Xuebao, Nr. 4, 1980, pp. 149-160

Country of origin: China
Translated by: FLS, INC.
F33657-85-D-2079
Requester: FTD/WE
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SOME CLIMATOLOGICAL FEATURES OF ATMOSPHERIC DIFFUSION CLASSES AT NANJING

Zhang Shifeng, Zhao Ming, Wang Yanchang*

This paper first modified the two methods which use routine meteorological data in determining the atmospheric diffusion classes to suit the application of our country. On this basis, we conducted statistical analysis of the one-year data in the Nanjing area to obtain some elementary climatological features of atmospheric diffusion classes at Nanjing, and compared the results of the above two classification methods.

I. PREFACE

The climatology of air pollution has gained more and more attention in air pollution problems. Environmental protection and planning and design of cities and industrial areas require the understanding and estimation of long-term atmospheric diffusion capability in these areas, and the possible pollution situations caused by it. Due to the lack of long-term pollution monitoring and special meteorological observation data, it has become quite necessary to analyze the relations between atmospheric pollution and routine meteorological data which have been accumulated throughout the years. Routine meteorological data commonly used are wind direction rose, small wind frequency and sustaining time, distribution of temperature inversion, etc. In order to analyze the overall air pollution climatological features of a certain area and further to estimate the long-term average concentration of that

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area, climatological analysis of atmospheric diffusion classes (dtermined by routine meteorological data) must be conducted[1]. This analysis can also give a total assessment of the capability of atmospheric diffusion and find out the features of its changes with respect to time, thereby providing information for emission control and pollution forecast. The method of estimating pollution concentration through the determination of atmospheric diffusion classes using routine meteorological data was first proposed by Pasquill[2]. Shortly afterward, Gifford[3] modified this method to give the diffusion coefficient values with respect to short distance change under different diffusion classes. But the P-G method is unrefined in determining radiation classes, and later a method using specific altitude angle of the sun and cloud conditions was developed. We called the two models [4][5] method A and method B, respectively. The two methods are essentially the same, only different in details.

In recent years, our country had performed estimation of local air pollution concentration using the above method, and, in general, the results were fair. The method does not require special meteorological observation and is simple to use, therefore it has valuable practical use.

This paper made some modifications to the aforementioned two methods, which use altitude of sun, cloud conditions and wind speed to determine diffusion classes, to suit the application of our country. On this basis, we conducted statistical analysis of the one-year continuous data in the Nanjing area to obtain some elementary climatological features of atmospheric diffusion classes at Nanjing and compared the results of the above two classification methods.

II. DETERMINATION OF ATMOSPHERIC DIFFUSION CLASSES

The A and B methods were originally designed for use in western countries. For example, wind velocity is expressed in

miles/hr; altitude of cloud in feet, etc. It is quite inconvenient for us to use these units in setting the classes. In addition, we express wind velocity in the unit of meters/sec and round it off to integer. Thus, when converting units, the wind velocity range (miles/hr) corresponding to a certain wind velocity (meters/sec) may include wind velocities which correspond to two classes in the original standard, and therefore make it difficult to set the class. Moreover, there are numerous ambiguous and incomplete places in the original classification standard. Therefore, we made some modifications based on the original classification standard[4,5] to convert units of meteorological data into units used in our country and also clearly set and adjusted class borderlines which were vague. The classification standards after modification for methods A and B are shown in Tables 1 and 2, respectively. Considering the fact that the method for estimating pollution concentration using diffusion classification is a rough approximation and that our modificatio-s were not drastic, the original value for the diffusion parameter corresponding to each diffusion class was used. Of course, further investigations are needed to determine whether the modificaitons we made are appropriate. Hereinafter, the modified methods A and B are simply called methods A and B.

When several kinds of clouds appear simultaneously, the heights of clouds in Tables 1B and 2A that represent those of the largest amount of clouds should be selected. Of course, reasonable selection also needs to be made for cases of a single kind of cloud.

Table 1A. Method A after modification - I is determined by θ

(a) 太阳高度θ	$0° < \theta \leq 15°$	$15° < \theta \leq 35°$	$35° < \theta \leq 60°$	$60° < \theta$
(b) 日射级别 I	1	2	3	4

Key: (a) Altitude angle θ of the sun; (b) Sun incidence class I.

Table 1B. Method A after modification - Radiation classes **S** are determined by I.

(c) 时间	(a) 总云量	(b) 云底高H（米）	S	(f) 备注
(d) 白天 (θ>0°)	≤5	任意 (h)	S=I	(g) 若S<1 则取S=1
	6,7,8,9,	5000≤H	S=I	
		~~2000<H<5000~~	~~S=I-1~~	
		H≤2000	~~S=I-2~~	
	10, 10	2000<H	S=I-1	
		H≤2000	S=0	
(e) 夜间 (θ≤0°)	≤4	任意 (h)	S=-2	
	5,6,7,8,9	任意 (h)	S=-1	
	10, 10	2000<H	S=-1	
		H≤2000	S=0	

Key: (a) Total amount of cloud; (b) Altitude of clouds H(meter); (c) Time; (d) Day; (e) Night; (f) Comments; (g) If S< 1, then set S=1; (h) Any.

Table 1C. Method A after modification - Diffusion classes are determined by S and ground wind velocity V(meters/sec).

V \ S	4	3	2	1	0	-1	-2
0	1	1	2	3	4	6	7
1	1	2	2	3	4	6	7
2	1	2	3	4	4	5	6
3	2	2	3	4	4	4~5	5~6
4	2	3	3	4	4	4	5
5	3	3	4	4	4	4	5
6	3	3	4	4	4	4	4
8	3	4	4	4	4	4	4

Table 2A. Method B after modification - the determination of radiation classes (night is defined as when $\theta = 0^{\circ}$)

(a) 云况		(b) 夜间	(c) 太阳高度角 θ			
(d) 总云量	(e) 云底高H(米)		$\leq 15^{\circ}$	$15^{\circ} < \theta \leq 35^{\circ}$	$35^{\circ} < \theta \leq 65^{\circ}$	$> 65^{\circ}$
0,1,2,3	(f) 任意	-2	0	+1	+2	+3
4,5	(f) 任意	-1	0	+1	+2	+3
6,7,8,9	≥5000	-1	0	+1	+2	+3
	2000<H<5000	-1	0	0	+1	+1
	≤2000	0	0	0	0	+1
阴天	>2000	-1	0	0	0	+1
	≤2000	0	0	0	0	0

Key: (a) Cloud conditions; (b) Night; (c) Altitude angle θ of the sun; (d) Total amount of cloud; (e) Altitude of cloud H(meters); (f) Any.

Table 2B. Method B after modification - Diffusion classes are determined by R and ground wind velocity V.

V (a) \ R	+3	+2	+1	0	-1	-2
≤1	A	A-B	B	D	E	F
2	A-B	B	C	D	E	F
3,4	B	B-C	C	D	D	E
5,6	C	C-D	D	D	D	D
>6	C	D	D	D	D	D

Key: (a) meters/sec.

III. PROCESSING OF DATA

The Nanjing Grand field weather station conducted 24 meteorological observations daily (one every hour). The quality of cloud observation was also quite high. We employed its data for a one-year period from December 1, 1976 to November 30, 1977. There were only 46 hours of data missing, giving 8714 hours of usable data. For an annual data, this was quite complete.

The diffusion class for every hour in the aforementioned one-year data was sequentially determined using the classification standards of Tables 1 and 2. And then statistical analysis was conducted for the diffusion classes.

The height of the sun used in the classification process can be calculated from the following formula:

$$\sin\theta = \sin\varphi\sin\delta + \cos\varphi\cos\delta\cos\tau$$

where ϕ is the geographical latitude, δ is the sun's equatorial latitude and τ is the loca time angle. Calculations were conducted graphically. In the so-called Nabakov[6] graph, curves between θ and τ were made and θ could be determined using the τ values at each time instant immediately from the predrawn curves. Since τ is a local time time angle and the meteorological data are based on Beijing time, a time difference of 5 minutes should be considered for the Nanjing area.

IV. CLIMATOLOGICAL FEATURES OF DIFFUSION CLASSES

(1) Frequency distribution and annual changes of diffusion classes.

Table 3 is the annual and monthly frequency distributions of various atmospheric diffusion classes at Nanjing analyzed by using method A. Class 4 (neutral) is the most with 53.1%; the sum of class 1, 2 and 3 (unstable types) is the least with 17.5%; the sum of class 5, 6 and 7 of the stable types is second with 29.3%. Most of the unstable types belong to class 3 (weak unstable). Class 1 of the strong unstable type is extremely rare with only 0.8%. The percentages of class 5, 6 and 7 in the stable type are about the same. Since the neutral situation exceeds half of the total number, it can be said that the capability of atmospheric diffusion at Nanjing is, on the average, medium. This corresponds well to the geographical latitude and the climatological conditions of Nanjing. Its annual distribution of atmospheric diffusion classes is very similar to that of the

American city of Oakland[7].

Table 3. Frequency (%) of various diffusion classes under method A.

(b) 类别 / (a) 时间	(c) 不稳定				(d) 中性	(e) 稳定				(f) 观测次数
	1	2	3	Σ	4	5	6	7	Σ	
全年	0.8	4.5	12.2	17.5	53.1	8.4	11.9	9.0	29.3	8711
1月	0	2.8	8.7	11.5	64.2	5.1	12.3	7.0	24.4	727
2月	0.3	5.8	16.0	22.1	36.7	10.5	18.7	11.9	41.1	655
3月	0.3	1.3	6.7	8.7	69.6	7.5	7.3	6.9	21.7	734
4月	0.4	3.6	11.0	15.0	64.7	4.4	8.7	7.2	20.3	720
5月	2.2	5.8	10.6	16.6	65.5	6.9	6.4	4.7	18.0	744
6月	2.8	7.2	11.4	21.4	54.0	9.7	11.0	3.9	24.6	720
7月	1.1	5.5	16.0	22.6	53.0	9.7	12.4	2.4	24.5	744
8月	0.4	3.5	9.8	13.7	58.7	9.6	9.6	8.3	27.5	744
9月	0.6	5.3	21.4	18.2	53.9	7.4	13.8	6.8	27.9	720
10月	1.1	5.4	13.9	20.4	39.5	11.9	15.2	13.1	40.2	712
11月	0.6	6.3	18.6	25.4	30.6	8.1	12.8	23.1	44.0	720
12月	0	4.2	11.4	15.6	45.4	10.1	15.6	13.3	39.0	744

Key: (a) Time; (b) Class; (c) Unstable; (d) Neutral; (e) Stable; (f) Number of observations.

From Table 3 it can be seen that the change from month to month of each diffusion class is quite large, especially for class 1.7 it could differ several folds. This is because class 1.7 requires extreme meteorolgical conditions, and these conditions could differ much every month. Figure 1 shows the frequency distribution of seasonal atmospheric diffusion classes for spring (March, April, May), summer (June, July, August), fall (September, October, November) and winter (December, January, February).

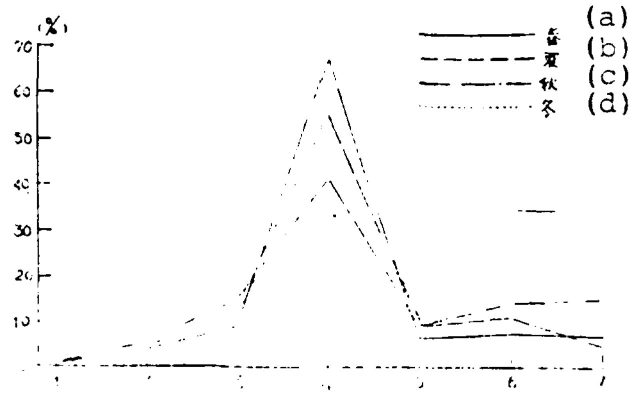


Fig. 1. Frequency distributions of seasonal atmospheric diffusion classes at Nanjing
Key: (a) Spring; (b) Summer; (c) Fall; (d) Winter.

From Table 3 and Fig.1, we can observe that stable classes appear the most in November and the fall, not the winter when the altitude of the sun is lower and day time shorter. Similarly, the unstable classes also appear the most in November and the fall, not June and summer when the height of the sun is higher and day time longer. The following reason might have caused this phenomenon. Although day light is shorter in winter and longer in summer, the least amount of clouds appears in the fall and in November, causing the highest and lowest radiation situations to occur more in the fall, and wind velocity in November and the fall is also smaller, thus making unstable and stable classes to occur easier. Yet the fact that more clouds appear in summer and wind velocity is greater in winter inhibits unstab'` and stable classes to occur, hence creating the aforementioned seasonal distribution. As to the neutral conditions, they occur in March and spring the most, which match the results derived from common climatological consideration (e.g.medium day light, largest wind velocity in the entire year). Percentages of stable and unstable classes are high in the fall, thus causing the neutral classes to occur the least.

It can be observed from the above analyses that the seasonal changes in the capability of diffusion at a certain location must be considered along with the climatological and meteorological features of that location. The above climatological features

of wind and cloud conditions at Nanjing are consistent with the results obtained throughout the years[8], and are thus representative.

Table 4 is the frequency distributions of each diffusion class obtained from method B, and they are similar to those of Table 3. There is one special point and that is that the frequency for neutral class (D class) is higher than that obtained from method A. This is true for every month. This matches Portelli's conclusion[9] indicating that the Pasquill classification method often exaggerates the neutral class.

Table 4. Frequency (%) of various diffusion classes under method B

(c) 类别 / (a) 时间	(b) 不稳定 A	B	C	Σ	(d) 中性 D	(e) 稳定 E	F	Σ	(f) 观测次数
全年	0.6	4.5	7.0	12.1	61.2	15.4	11.4	26.8	8711
1月	0.2	2.5	3.3	6.0	70.4	15.3	8.4	23.7	727
2月	0.6	5.8	8.3	14.7	47.6	21.5	16.2	37.7	653
3月	0.3	1.7	3.1	5.1	76.7	8.4	9.8	18.2	734
4月	0.3	3.5	6.7	12.5	71.5	9.2	8.9	18.1	720
5月	1.6	4.6	6.7	12.9	71.4	9.9	5.8	15.7	744
6月	1.5	5.8	8.9	16.2	63.3	15.3	5.3	20.6	720
7月	0.3	5.0	10.8	16.1	62.9	17.2	3.9	21.1	744
8月	0.3	3.8	5.4	9.5	66.9	14.7	9.0	23.7	744
9月	0.3	4.9	6.2	11.4	61.9	17.5	9.2	26.7	720
10月	0.9	5.9	8.0	14.8	47.6	21.4	16.2	37.6	742
11月	0.8	6.3	11.0	18.1	39.1	16.1	26.8	42.9	720
12月	0.1	4.1	5.9	10.1	53.2	18.3	18.4	36.7	744

Key: (a) Time; (b) Unstable; (c) Class; (d) Neutral; (e) Stable; (f) Number of observations.

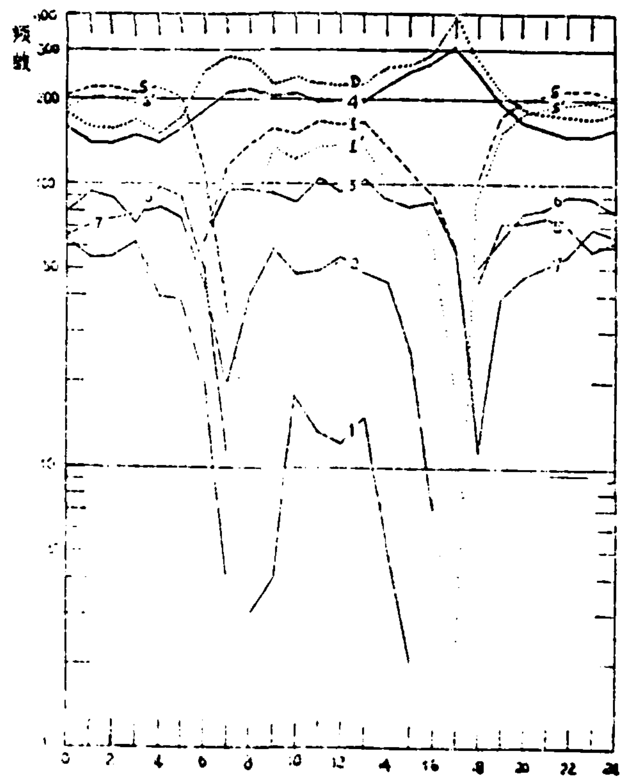
(2) Daily changes of diffusion classes

Figure 2 shows the daily frequency changes of atmospheric diffusion classes at Nanjing. The numbers on the curves indicate classes using method A. I represents the sum of class 1, 2 and

3. S represents the sum of class 5, 6 and 7. Only D class, I' (sum of A, B and C classes) and S' (sum of E and F classes) are drawn using the P-G method.

Figure 2 shows that unstable conditions only occur in the day time (6:00-18:00 hours), stable conditions only between dusk and morning (16:00-8:00 hours) and neutral conditions at any time of the day. These are consistent with the daily changes in meteorological conditions. The daily changes in the frequency of neutral conditions are small with the largest frequency occurring at 17:00 hours and the smallest at 4:00 hours. The largest frequency for unstable conditions occurs between 12:00-13:00 hours and the samllest between 17:00-18:00 hours. The largest frequency for stable conditions occurs at 4:00 hours and three-four hours later, i.e.after sunrise, it rapidly drops to the smallest. Both daily changes of the unstable and stable types are quite large.

(a)



(b)

Fig.2 Daily changes in frequency of atmospheric diffusion classes at Nanjing (1976, 12 - 1977, 11)
Key: (a) Frequency; (b) Time.

(3) Relations between diffusion classes and wind direction

In addition to conditions of the pollution source, it is usually necessary to know the diffusion classes and the combined probability distribution density of wind direction and wind velocity in order to obtain the air pollution climatological concentration of a certain place under given conditions. Due to limitation in time and data, we did not obtain statistical three-dimensional distribution density. As a preliminary effort, we only obtained combined frequency distribution of wind direction. See Table 5 for results (only results of method A are listed).

Table 5. Diffusion classes and combined frequency distribution of wind direction using method A

(b) 级别 / (a) 风向	1	2	3	4	5	6	7	Σ
N	1	5	35	298.5	23.5	23	7	393
NNE	3	7	31	278	21.5	22.5	7	370
NE		16	73	689.5	84	53.5	21	937
ENE	2	19	60	538.5	111	88.5	26	845
E	1	23	66	516.5	85	69.5	17	778
ESE	4	24	71	565	76.5	42.5	18	801
SE	1	38	98	290	80.5	55.5	19	582
SSE		30	61	106.5	40.5	38	16	292
S	3	29	75	128.5	41	42.5	16	335
SSW	3	9	39	64	23	27	6	171
SW	1	18	62	145	41	34	17	318
WSW	1	17	50	159.5	39	24.5	7	298
W	3	21	32	183	22.5	22.5	8	292
WNW	3	7	37	86.5	8.5	5	4	151
NW		10	23	138	20	12	5	208
NNW		6	27	181.5	13	15.5	6	249
C	46	117	229	261	1	163	463	1694
Σ	72	396	1060	4629.5	731.5	1039	786	8714

Key: (a) Wind direction; (b) Class.

It can be observed in the table that, although various diffusion classes can almost occur under any wind direction, the changes in the frequency distribution based on wind direction for every class are great. The difference between the largest and smallest frequency distribution can be greater than one order of magnitude. The more distinctive one among them is that the highest frequency occurs under class 4 and NE wind and the lowest under SSW wind. Another special point is that, except for class 4 and 6, the frequency of every class, under calm wind (C), is high. Part of the reason is that the frequency under calm wind in the Nanjing area is inherently high, about 19.4%; another reason is that the diffusion classes on both ends, especially class 7, can only occur under very small wind speed (including calm wind); therefore, the occurrence frequency of class 7 under calm wind reaches as high as 74.6%.

It can also be observed from the table that, under different wind direction, class 4 has the highest frequency; and, under calm wind, class 7 has the highest frequency.

V. COMPARISON OF THE TWO CLASSIFICATION METHODS

In order to further compare the results of the two classification methods, we analyzed the corresponding statistical class relations between the two. As shown in Table 6, each row represents the frequency of each method A class corresponding to different method B classes, and each column represents the frequency of each method B class corresponding to different method A classes.

Table 6. Comparison of results of classification methods A and B

A \ B	A	B	C	D	E	F	Σ
1	31	41					72
2	19.5	299.5	66	11			396
3		47	520.5	471.5	21		1060
4		2.5	23.5	4574.5	29		4629.5
5				233.5	498		731.5
6				33	745	261	1039
7				6	45	735	786
Σ	50.5	390	610	5329.5	1338	996	8714

When class 1-6 of method A is compared to class A-F of method B, respectively, 71% of the total number correspons perfectly for the entire year. 27.7% differs by one class between the two methods; 1.3% by two classes; and less than 0.1% by three classes. Thus, the results of the two classification methods are, in general, consistent. It can be observed in the table that, although the majority of class A corresponds to class 1, the majority of class 1 corresponds to class B. Moreover, class E does not correspond primarily with class 5 but with class 6. Class F, in fact, corresponds to class 7.

For neutral conditions, 98.8% of class 4 corresponds to class D. Situations where class 4 corresponds to two classes from D class (i.e. class 4 corresponds to class B) are extremely rare. However, the percentage of cases where class D corresponds to class 4 is less than 86% with about 1% corresponding to unstable, stable or strong stable classes. Thus in the correspondence relations between the two, class D under method B is more scattered than class 4 under method A.

Considering these situations and the results obtained earlier, we believe that method A is the better one between the two

classification methods. Of course, which one is really better will have to be determined eventually by diffusion tests and pollution concentration data.

VI. CONCLUSIONS

More than half of the lower atmospheric diffusion classes (diffusion capability) in an entire year at Nanjing belong to neutral situations (class 4 or class D). The total diffusion capability can be considered as medium. Both unstable and stable situations occur the most in the fall (especially in November) and the least in spring; for neutral situations, they occur the most in spring and the least in the fall. These seasonal changes are determined by the climatological conditions of the Nanjing area. The unstable situations always occur in the day time and stable ones always between the period from dusk to morning; neutral situations can occur at any time with less daily changes. Occurrence frequency of each diffusion class changes greatly as wind direction changes. For both unstable and stable situations, the frequencies under calm wind are extremely high, therefore, the atmospheric diffusion and air pollution under calm wind situation at Nanjing are worth paying attention to. The comparison of the two classification methods indicates that method A is better.

Due to the limitation in data, our results are just preliminary. Data collected over a longer period of time are required to conduct further study. We made modifications to the original classification methods and their accuracy requires verification by diffusion data. Since the two original methods A and B were for flat under side and the fact that the Nanjing area includes both flat and rough under side, their accuracy still requires further verification for the implementation at rough areas in and around Nanjing. But in general, the results of this paper gave a general

picture of what the climatological features of atmospheric diffusion are at Nanjing.

If the source data are available, some of the results proposed by this paper can be used to determine preliminarily (then with more complementary calculations) and forecast the climatological concentration of air pollution of a certain area. Meanwhile, some of the climatological features of atmospheric diffusion at Nanjing can also be referenced to develop future potential air pollution forecast, emission control from production facilities and pollution prevention.

Appreciation announcement: We hereby express our thanks to Comrade Bang Yunxian and Li Zhongka who provided a great deal of care and assistance, and Comrade Ye Pinhua who plotted the figures. The authors especially appreciate the data and convenience enthusiastically provided by the Nanjing Grand Field Weather Station, and hereby express our special thanks.

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ASD/FTD/TQIA	1

END

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